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CAPACITIVE CHARGE DIVISION IN CENTROID FINDING CATHODE READOUTS IN MWPCs*

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Abstract

A technique is described in which the centroid of induced charge on cathode strips in a proportional chamber can be determined with reduced differential and integral nonlinearity, without increasing the number of readout channels. It is based on capacitive charge division from intermediate cathode strips to adjacent readout strips, and may be applied to a variety of position readout principles.

Introduction

Position sensitive wire proportional chambers are used extensively in high energy physics for particle localization, and in biology for x-ray localization in small angle scattering and protein crystallography experiments. Sampling of the induced charge on cathode strips, or groups of cathode wires, is a commonly used technique to determine the position of an anode avalanche created by the incident radiation.

The quasi-Lorentzian profile of the cathode induced charge has a FWHM approximately one and a half times the anode cathode spacing, d. Differential nonlinearity of the position readout is caused by systematic shifts of the centroid of induced charge on the cathode strips from the centroid of the true induced charge profile. When the strip pitch is too large nonlinearity occurs in the form of modulation of the position output with a period equal to the strip pitch. Assuming that all the induced charge is sampled by the position readout, then if w = strip pitch, differential nonlinearity is generally negligible only when $w/d \lesssim 0.8$.

In high energy physics applications, detectors often have several hundred or thousand readout channels. Methods are required to reduce the number of channels to minimize complexity and cost, but preferably without increasing nonlinearity. In x-ray diffraction studies it is important that the detector have extremely low differential nonlinearity so that small diffraction peaks are unambiguously distinguishable from the background. However, there is still a need to minimize the number of cathode readout channels, especially with position sensing by delay line where the number of readout sections is limited.

Several techniques have been described which address the problem of maintaining low differential nonlinearity with a reduced number of readout channels. In methods which use an amplifier per channel a strip pitch larger than advised by the above inequality is often used and an attempt is then made to reduce the increased nonlinearity with special electronic analysis. A fixed bias may be applied to the output of each readout element [1,2], or a special algorithm can be used to optimize the correction that is required [3] or signals can be analyzed by a special interpolating filter [4]. An increase in cathode strip pitch by a factor $\lesssim 2$ is possible but at the expense of a more complex reconstruction procedure. Moreover, these methods are not easily applicable to global readout, e.g., delay line, without increasing nonlinearity. A method which is easily applicable to global readout, but which was actually demonstrated with an amplifier per channel system, has cathode strips with zigzag edges [5] instead of the usual straight edges. Although it was used primarily to improve position resolution, it succeeded in reducing the number of readout channels by about 20%.

We describe in this paper a new method of reducing the number of cathode readout elements by up to a factor two, without increasing differential nonlinearity, which can be applied both to amplifier per channel systems and to global position readout. Its performance has been studied in both types of readout, is quite simple to construct, and does not require modification of the existing readout electronics.

Cathode Induced Charge Distribution

It is helpful to have a method by which the position response of a particular cathode strip configuration can be predicted. To achieve this it is necessary to derive a function which describes the spatial distribution of the cathode induced charge. There have been, recently, several such calculations of the induced charge, for example see Ref. 2, 6, 7 and 9. In some of these calculations account is taken of factors such as the time change in the cathode charge distribution as positive ions move away from the anode wire, and of the effects of anode avalanche angular localization, and of the differences between continuous cathodes and wire cathodes. Although these variables are important, they do not result in major changes to the shape of the induced charge distribution for normal operating conditions. A detailed study of the effects of these variables, (Ref. 8 and 9), resulted in a simplified expression for the induced charge distribution on a continuous cathode, and assumed that the avalanche uniformly surrounded the anode wire. If the x-direction is defined to be parallel to the anode wires then the magnitude of the cathode charge distribution, Γ_1, as a function of $\lambda = x/d$, is given by

$$\Gamma_1(\lambda) = K_1 \frac{1 - \tanh^2(K_2\lambda)}{1 + K_3 \tanh^2(K_2\lambda)}$$

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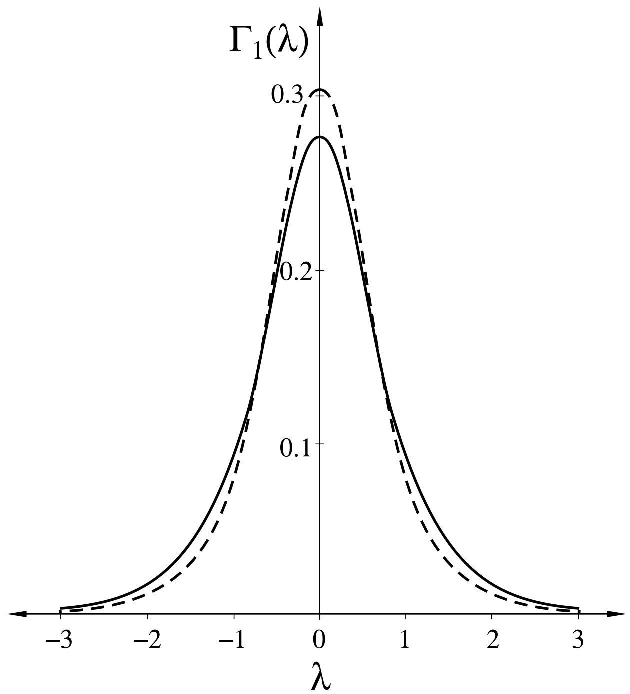


Fig. 1. Cathode induced charge distribution, $\Gamma_1(\lambda)$, as a function of $\lambda = x/d$, where x is the direction along the anode wire, d = anode-cathode spacing. The solid curve is the distribution for the geometry of the test chamber: $r_a = 6.25\ \mu$m, $d = 1.59$ mm, anode wire pitch, $s = 2.8$ mm ($d/s = 0.56$). The dashed curve shows how the distribution becomes slightly narrower if the anode wire pitch is reduced ($d/s = 1.5$).

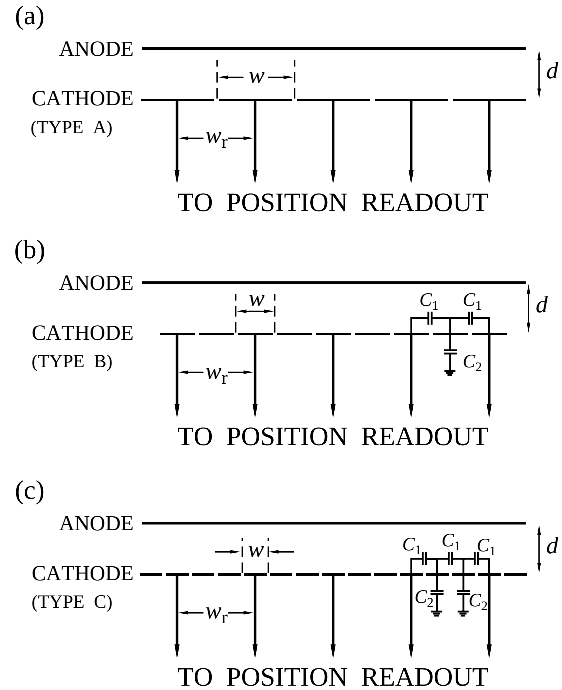


Fig. 2 (a) Normal readout from cathode strips, type A cathode. Every strip is fed to the position readout and strip pitch w, equals the readout pitch, w_r.
(b) New readout technique, type B cathode. Readout pitch remains the same as cathode A but the strip pitch is halved so that $w = w_r/2$. C_1 = interstrip capacitance and C_2 = intermediate strip capacitance to ground.
(c) Type C cathode, in which readout pitch remains the same as type A cathode, but strip pitch is reduced by a third so that there are now two intermediate strips between readout strips. C_1 = interstrip capacitance and C_2 = intermediate strip capacitance to ground.

where K_1, K_2, K_3 are constants dependent upon the MWPC geometry. The continuous curve in Fig. 1 illustrates this function for the geometry of the chamber used in our cathode tests described later.

Cathode Strip Readout—Calculated Performance

Normal Method

Figure 2(a) illustrates the usual cathode strip arrangement where the signal from each strip is fed into the readout system. We will refer to this as a type A cathode. The strip pitch, w, is equal to the readout pitch, w_r. The charge from each strip may be collected by preamplifiers in the case of amplifier per channel readouts, or may go to the nodes of a delay line, or resistive line, for global readouts.

Using the charge distribution in Fig. 1, the quantity of charge induced on each strip can be evaluated. The mathematical, or measured, centroid, x_m, of each event of a uniform set of events along the anode wire can then be found. If x is the true position of the avalanche, the relationship between x_m and x just repeats between each adjacent pair of readout channels. The variation in the derivative of the function $x_m = f(x)$ represents the differential nonlinearity of the system. We will measure differential nonlinearity in terms of the maximum deviation (plus and minus) of this derivative from its value for an ideal system. Assuming that all the induced charge is sampled by the position readout the differential nonlinearity of type A cathode, as a function of w/d, is shown by the continuous curve in Fig. 3 for $d/s = 0.56$, the value for our test chamber.

Differential nonlinearity is a relatively weak function of d/s. Nevertheless as d/s increases, the width of the induced charge distribution decreases and differential nonlinearity increases, for a given cathode strip pitch. The dashed curve in Fig. 1 shows the induced charge distribution for $d/s = 1.5$, and the corresponding nonlinearity is shown by the dashed curve in Fig. 3.

It can be seen that a ratio $w/d \sim 0.8$ results in negligibly small differential nonlinearity.

New Method

In the new arrangement of cathode strips, each of the original readout strips is halved in width and a floating, or

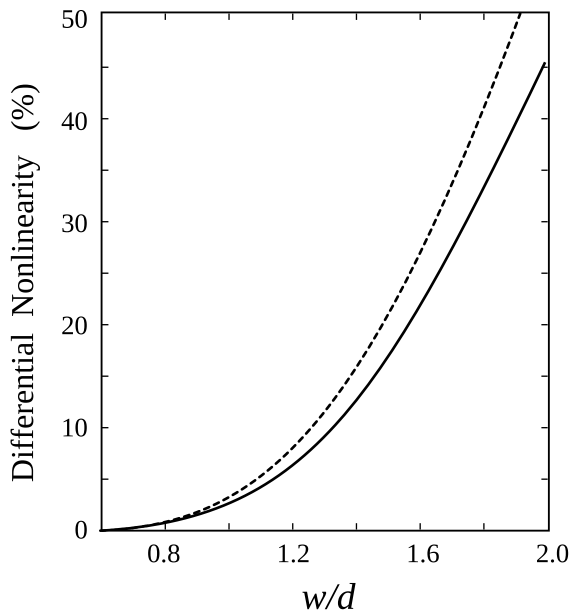


Fig. 3 Solid curve shows variation of differential nonlinearity with w/d for type A cathode, with $d/s = 0.56$, value for the test detector. The dotted curve shows the effect of reducing anode wire spacing, $d/s = 1.5$.

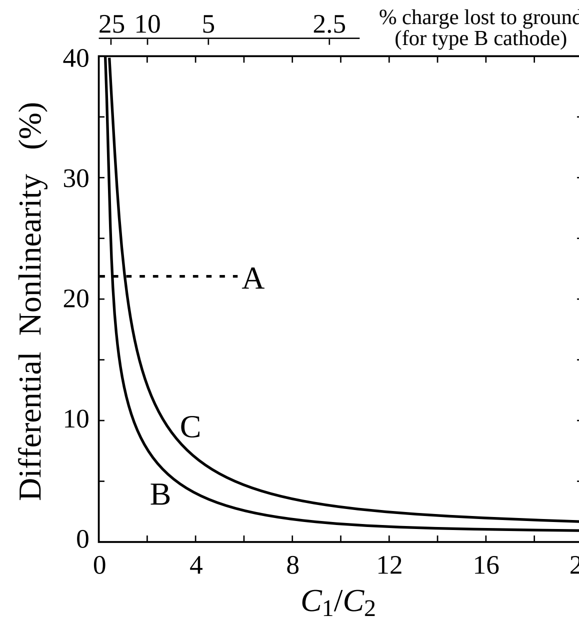


Fig. 4 Calculated differential nonlinearity for type B and C cathodes in the test detector as a function of C_1/C_2. The dotted line shows the calculated differential nonlinearity for type A cathode.

intermediate strip, is placed in between each readout strip. The layout is shown in Fig. 2(b), and we will refer to this as type B cathode. The readout pitch, w_r, is unchanged from the normal method, and the strip pitch, w, is halved. Charge induced on each intermediate strip is capacitively coupled to its neighbor on either side, depending upon the magnitudes of C_1, the interstrip capacitance, and C_2, the intermediate strip capacitance to ground.

The fraction, F_1, of charge from the intermediate strip which is coupled to each neighboring readout strip is given by

$$F_1 = \frac{C_1}{2C_1 + C_2}$$

and the fraction, F_2, of charge from each intermediate strip coupled to ground is given by

$$F_2 = \frac{C_2}{2C_1 + C_2}$$

It is important to minimize the value of C_2 to ensure that most of the charge is coupled to the readout strips. In the limit as $C_1/C_2 \to \infty$, one obtains perfect charge division and position linearity is the same as if all strips were directly read out. Using the same centroid analysis as described in the previous section, the predicted differential nonlinearity of type B cathode configuration has been calculated, in Fig. 4 and is shown as a function of C_1/C_2, using the parameters of our test chamber. The dotted line in the same figure shows the predicted nonlinearity for the equivalent type A cathode with the same value of w_r. It is clear that if C_1/C_2 exceeds ~0.5, then type B cathode is superior to type A in terms of nonlinearity, and when C_1/C_2 is above about 2 the improvement in nonlinearity is considerable. It should b noted that when $C_1/C_2 < 2$, a significant fraction of cathode charge is lost to ground and therefore reduction in signal to noise will begin to degrade position resolution. On average the percentage charge coupled to ground is $100 \times F_2/2$, and is indicated at the top of Fig. 4. Cathodes with $C_1/C_2 > 2$ lose so little charge to ground that position resolution is essentially unaffected.

It is natural to consider, next, using two intermediate strips between each readout strip. This arrangement, which we will designate as a type C cathode, is shown in Fig. 2(c). The readout pitch, w_r is still the same as for the type A and B cathodes, but the strip pitch, w, is now one third that of the type A cathode. The fraction of charge, F_3, coupled from an intermediate strip to its near readout neighbor is

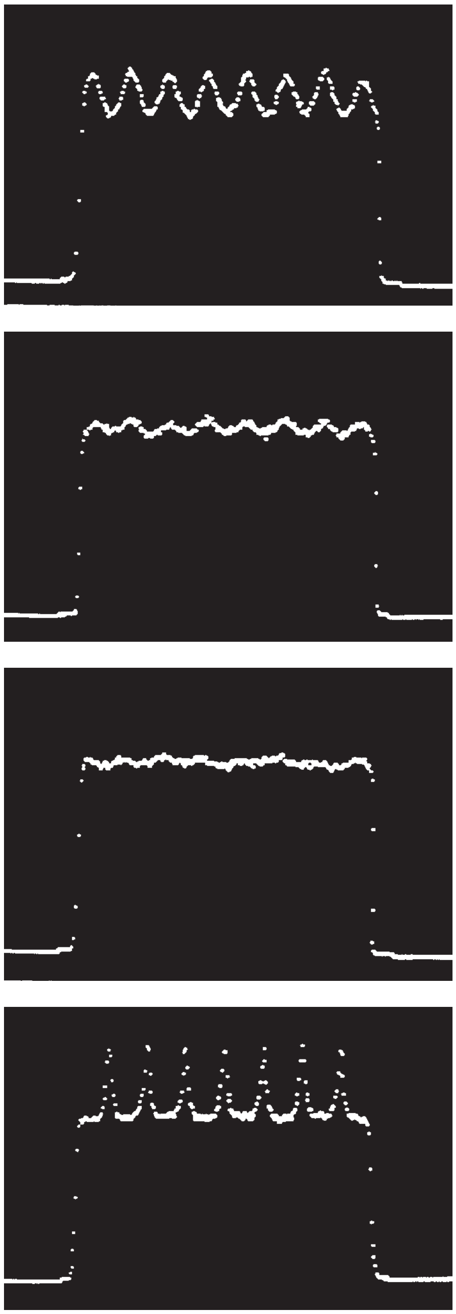
$$F_3 = \frac{2C_1^2 + C_1C_2}{3C_1^2 + 4C_1C_2 + C_2^2}$$

and the fraction of charge, F_4, coupled to its far readout neighbor is

$$F_4 = \frac{C_1^2}{3C_1^2 + 4C_1C_2 + C_2^2}$$

Each intermediate strip loses a fraction of charge, F_5, to ground given by

$$F_5 = \frac{C_2^2 + 3C_1C_2}{3C_1^2 + 4C_1C_2 + C_2^2}$$



(a) (b) (c) (d)

Fig. 5 Position spectrum from detector when uniformly illuminated with x-rays.

a) with type A cathode, $w/d = 1.6$. Differential nonlinearity ~23%.

b) with type B cathode, $w/d = 0.8$. $C_1/C_2 \sim 3$. Differential nonlinearity ~8%.

c) with type B cathode, $w/d = 0.8$. $C_1/C_2 \sim 10$. Differential nonlinearity ~5%.

d) with type B cathode, $w/d = 0.8$. $C_1/C_2 \sim 3$. No high resistance coating.

Figure 4, again, shows the differential nonlinearity of a type C cathode vs C_1/C_2, for the geometry of our test chamber. It can be seen that, for a given value of C_1/C_2, the differential nonlinearity is larger than for a type B cathode. The quantity of charge coupled to ground is also greater. Therefore, we have not pursued the idea of two or more intermediate strips between readout strips, and have restricted our experimental investigations to cathodes of type A and B.

Apparatus

Cathode testing was carried out in an x-ray position sensitive detector that has been developed for small angle x-ray scattering experiments. It consists of a type A cathode, $w_r = w = 2.54$ mm which feeds a 40 tap, 1 μsec transit time delay line. The anode plane has a wire pitch 2.82 cm, the other cathode being a beryllium entrance window. Anode cathode spacing is normally 3.3 mm, yielding $w/d = 0.77$. The detector, therefore, has very low differential nonlinearity [10] (see Fig. 3).

For our present investigations the anode cathode spacing was reduced by more than a half to 1.59 mm, but otherwise the detector geometry was unchanged. For cathode type A, w/d was now 1.6 so that considerable differential nonlinearity would be expected. For cathode type B, w/d was 0.8. In addition to using delay line readout, the cathode strip signals could also be analyzed, individually, in an amplifier per channel centroid finding system, described in Ref. 11.

The detector was operated in flow mode with Ar/20% CO_2 and was uniformly illuminated with 5.4 keV x-rays from a distant x-ray tube. Differential nonlinearity was measured as the maximum deviation from a flat response of the uniform irradiation position spectrum.

Results and Discussion

Type A cathode was first tested, with delay line readout. Fig. 5(a) shows the recorded position spectrum - only eight readout sections of the cathode were illuminated to simplify the display. The maximum variation from a flat response is approximately 23% which is in close agreement with the calculated result in Fig. 4.

Several versions of type B cathode were fabricated, to investigate maximization of the ratio C_1/C_2. They all had $w_r = 2.54$ mm and $w = 1.27$ mm, but the actual width of each strip, which was constant on any one cathode, varied from 0.635 mm to 1.21 mm. C_1 and C_2 were measured with the cathode in situ in the detector. The value of C_1 was determined by fabricating a special cathode in which all the intermediate strips were connected together; all the individual C_1's were then measured in parallel, substantially reducing errors due to stray capacitance. The cathode version with the largest strip width, 1.21 mm, yielded the largest ratio C_1/C_2 of approximately 3. This was somewhat lower than expected, because of the difficulty in lowering C_2 due to the relative closeness of grounded metal used in the assembly of the detector. Figure 5(b) shows the position spectrum recorded by this cathode when the detector was uniformly illuminated with x-rays. The modulation is approximately 8%, considerably reduced from that of the type A cathode. The C_1/C_2 ratio was then increased to about 10 by attaching, with conductive epoxy, small chip condensers (4.7 pF) across the boundary between each intermediate and readout strip; they were placed at the edge of the cathode and did not affect the electric field in the active part of the detector. Figure 5(c) shows the position spectrum from this cathode. Modulation at the strip pitch is nearly absent and a nonlinearity of about 5% is achieved due to a combination of the modulation and delay line tolerances.

An essential feature of the correct operation of type B cathodes is a high resistance coating applied across all the strips. The purpose of this is to hold the intermediate strips at the same potential as the readout strips, which are well coupled to ground. An interstrip resistance of around 10 MΩ is low enough to perform this function, and is also high enough that the noise of the readout system is not affected. The resistance was produced by coating the active cathode area with carbon, using a carbon arc discharge under vacuum. If the restive layer is omitted, a highly non-linear position spectrum is produced, as shown by Fig. 5(d). This is due to electric field distortion in the detector which causes a disproportionate number of events to shift and create an avalanche above an intermediate strip.

The use of an amplifier per channel centroid finding type position readout with type B cathode produced essentially the same results as indicated in Fig. 5. There is, perhaps, less of a problem in applying this cathode readout technique to an amplifier per channel system than to delay line position sensing. With our present delay line, for example, the 25 nsec delay per section is achieved with 12.5 μH intersection inductance and a capacitance to ground per section of $C_S = 50$ pF. In order to avoid delay line dispersion, which would degrade position resolution, the intersection capacitance should be <10% of the section capacitance to ground, or about 5 pF in our example. The maximum value of C_1 in our case was nearly 7 pF, or an intersection capacitance of ~3.5 pF. If the total delay line transit time is reduced (to achieve higher counting rate capability), C_S also is reduced and the problem of combating dispersion while maintaining a high C_1/C_2 ratio is made more difficult.

In an amplifier per channel readout, the effect of the interstrip capacitance is to increase preamplifier noise, but the relatively small capacitance values involved will have minimal effect on noise.

In conclusion we have shown that the number of channels in a cathode strip position readout may be reduced by up to nearly a factor 2 by using intermediate, capacitively coupled strips, while maintaining a low differential nonlinearity. In detectors which have a large anode cathode spacing, and in which ground material can be kept well away from the cathode, acceptably high ratios of C_1/C_2 (~10 or greater) may be obtained from the cathode board itself. In cases where this is not possible, miniature condensers at the edge of the cathode board can be used to increase the ratio.

Acknowledgments

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